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Vertical Distribution of the Planktonic Stages of Penaeid Shrimp[1]

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Abstract

In an attempt to describe the vertical diurnal distribution of planktonic stages of penaeid shrimps, short research cruises into the Gulf of Mexico were made in June, July, September, and November 1963. The plankton was sampled systematically at a station 50 miles south of Galveston, Texas, where water depth approached 36.5 meters. Samples were obtained with a Clarke-Bumpus sampler at 4-hour intervals at each of three depths: 2, 18, and 34 meters. Bathythermograph casts were made prior to or at the completion of each collection.

During the first three cruises when temperature profiles and visual observations indicated a vertically stable water mass, catch data grouped for all stages indicated that planktonic penaeids were most frequent at and below mid-depth. Data arranged by developmental stage indicated, however, that protozoeal stages were found most frequently near the bottom whereas postlarval stages were at or above mid-depths. Each planktonic stage extended its distribution into the surface layer either just prior to or after darkness.

In November, when temperature profiles and visual observations indicated a vertically unstable water mass, planktonic-stage penaeids were more or less homogeneously distributed throughout the water column. There was no evidence of movement into the surface layer at night by any planktonic stage.

Introduction

Biologists at the Bureau of Commercial Fisheries Biological Laboratory in Galveston, Texas are engaged in a broad investigation of the seasonal as well as areal distribution and abundance of larval and postlarval penaeid shrimps in the northwestern Gulf of Mexico. Over the past two decades, studies of all phases of the life history of Gulf Penaeidae have received greater impetus as the commercial importance of many members of this family has increased. Prior to this period, information concerning young or larval penaeids in the Gulf of Mexico was restricted primarily to the work performed by Pearson (1939). He described the larval and postlarval stages of the white shrimp, *Penaeus setiferus,* and those of several other important penaeids occurring in the Gulf, including information on their growth and distribution as well. More recently, Dobkin (1961) outlined in detail the larval and postlarval stages of the pink shrimp, *Penaeus duorarum,* and Renfro and Cook (1963) described the early larval stages of the seabob, *Xiphopeneus krøyeri.* Very little information is available, however, concerning early stages in the life history of the brown shrimp, *Penaeus aztecus,* which in recent years has become the Gulf's most valuable commercial species.

It is generally believed that brown shrimp spawn in the open Gulf, sometimes as far as 110 miles offshore in depths to 110 meters. The eggs, slightly more dense than sea water, are deposited on the bottom. After hatching, the young planktonic shrimp develop through a series of three larval (nauplial, protozoeal, and mysis) and several postlarval

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stages. They enter the bays as advanced postlarvae where they grow rapidly to subadult size and subsequently migrate offshore to repeat their life cycle.

The movement of postlarval brown shrimp into estuarine nursery areas along the northwestern Gulf of Mexico appears to be a prerequisite for the production of their greatest biomass. Whether the planktonic stages are capable of extensive shoreward movement, whether water currents are largely responsible for their transport inshore, or whether both factors are important, is not known. Although Gurney (1924) and Koxon (1934) felt that the advanced stages of decapod larvae are not as much at the mercy of currents as might be supposed, the role of water currents in the distribution and survival of planktonic forms has been of considerable concern for a number of years. Colton (1959) provided evidence that the transport of planktonic fish eggs and larvae from the cooler waters of Georges Bank (Gulf of Maine) into the warmer Gulf Stream resulted in mass mortality. In a similar manner, water currents over the continental shelf in the northwestern portion of the Gulf of Mexico may be of considerable importance in the survival of planktonic penaeids. Because current direction and velocity may vary with depth, the importance of water currents can be properly assessed only after the position of the organism within the water column is known. This paper presents the results of four attempts to determine the vertical distribution of the planktonic stages of penaeid shrimp in the water column.

Materials and Methods

Short cruises with the Laboratory's research vessel were conducted in June, July, September, and November 1963 to a station 50 miles south of Galveston where the water depth approaches 36.5 meters (Fig. 1). Results of sampling in 1961 and 1962 had indicated that planktonic stages of penaeid shrimp usually could be found at this station at these times.

Plankton collections were made with a Clarke-Bumpus sampler whose frame was enlarged so that two nets could be mounted instead of one (Fig. 2). The mouth of each net had a cross-sectional area of 120.6 cm^2. Nets of No. 3 bolting silk (aperture 0.33 mm) were employed throughout the first three cruises, whereas, No. 2 nylon nets (0.36 mm) were used for the November collections. Since the samplers could be opened and closed at the desired depths, contamination with material from other depths while lowering or retrieving the gear was believed negligible.

Sampling covered 36 hours during the first cruise and 44 hours during each of the other three. Collections were made at 4-hour intervals at three depths: 2, 18, and 34 meters. Although samples were not taken at all depths simultaneously, every series was completed within an hour. Towing speed varied between 2 and 3 knots on a circular course around an anchored buoy. Bathythermograph casts were made either prior to or at the completion of each tow.

Plankton samples were preserved in 10% "buffered" formalin. In the laboratory, each sample was examined, and all penaeid larvae and postlarvae were removed, counted, and identified. Although four genera of shrimp were encountered (*Penaeus, Trachypeneus, Sicyonia,* and a few *Solencera*), analysis by individual genera was not attempted because of the small sample sizes.

Flow meters in the Clarke-Bumpus samplers were calibrated by the technique of

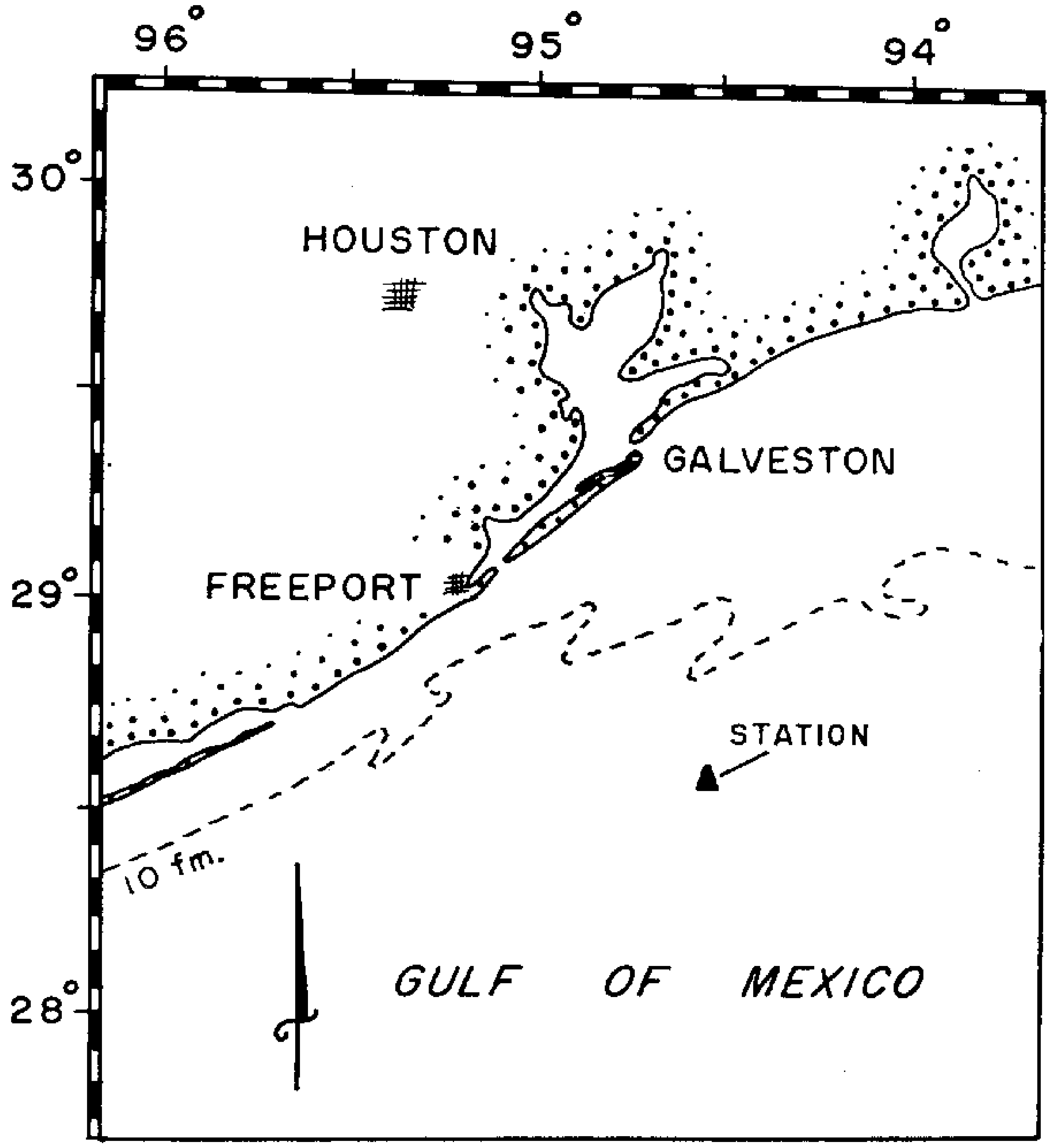

FIG. 1. Station occupied during vertical distribution studies.

Ahlstrom (1948). At speeds varying from 2 to 3 knots, each sampler filtered approximately 10 m^3 of water per 10-minute tow. Catch per tow as reported here consists of numbers per 20 m^3 of water filtered.

Data obtained during each cruise are presented by number, time, and depth of tow in Tables 1–4.

GENERAL DEPTH DISTRIBUTION

Although the abundance of planktonic stages varied during the June, July, and September cruises, the observed depth distributions of planktonic penaeids were similar (Fig. 3). Data grouped by stages show that immature (planktonic) penaeids were 2 to 4 times more abundant at the 18- and 34-meter depths than at the 2-meter depth. Protozoeal and mysis stages were found frequently in the deeper portions of the water column while postlarval stages occurred most frequently in the upper portion. The observed vertical distribution of the protozoeal and mysis stages agrees with the findings of Russell (1925, 1928) and Heegaard (1953). Russell, who dealt with larvae of several kinds of decapods, found the major concentrations of larvae nearer the bottom than the surface. Heegaard, who reported on larval *P. setiferus*, observed a similar depth distribution. The data presented in Fig. 3 also indicate that the vertical distribution of the planktonic stages is reversed as the shrimp grow from the protozoeal stage to the postlarval

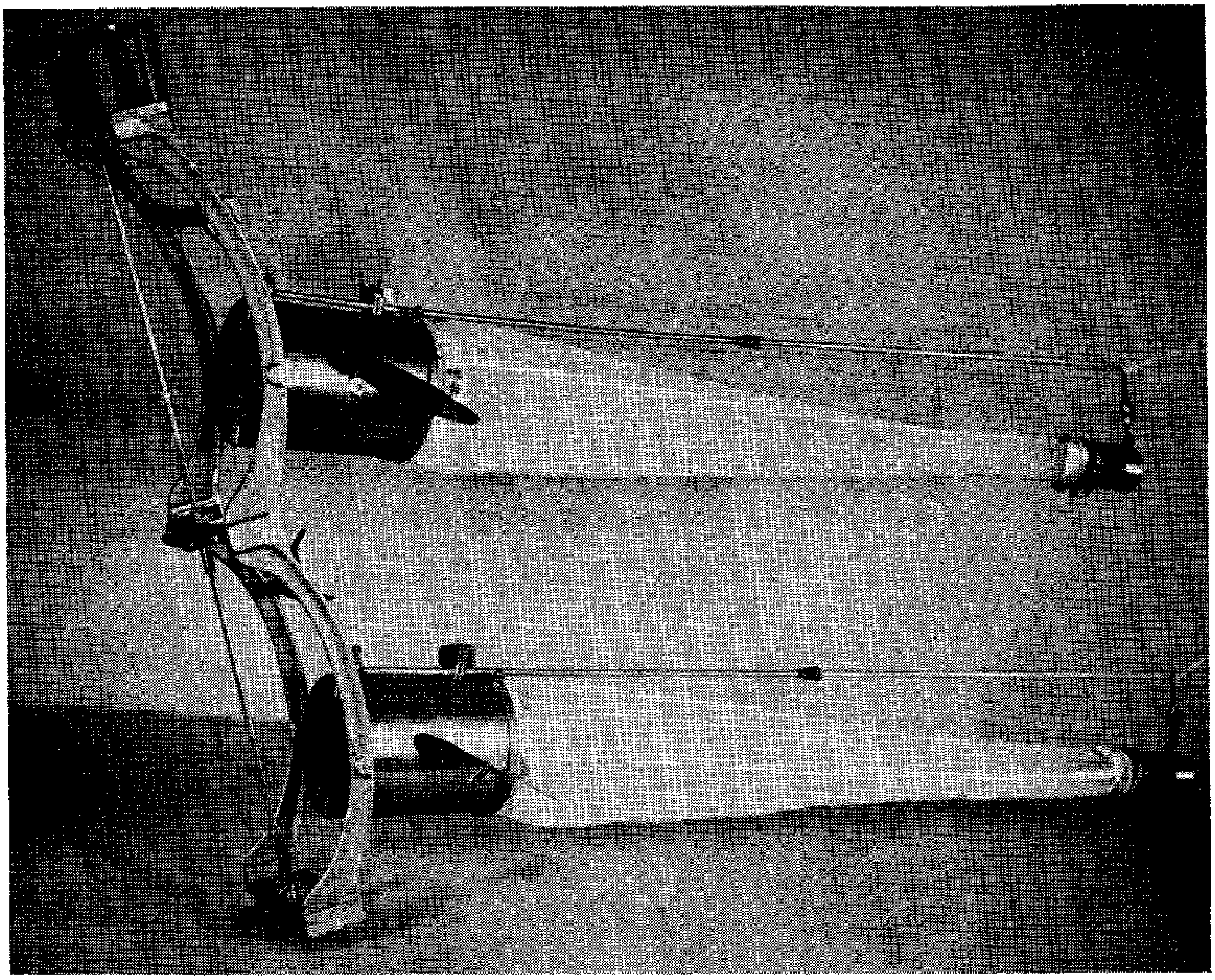

FIG. 2. Clarke-Bumpus sampler used in vertical distribution studies.

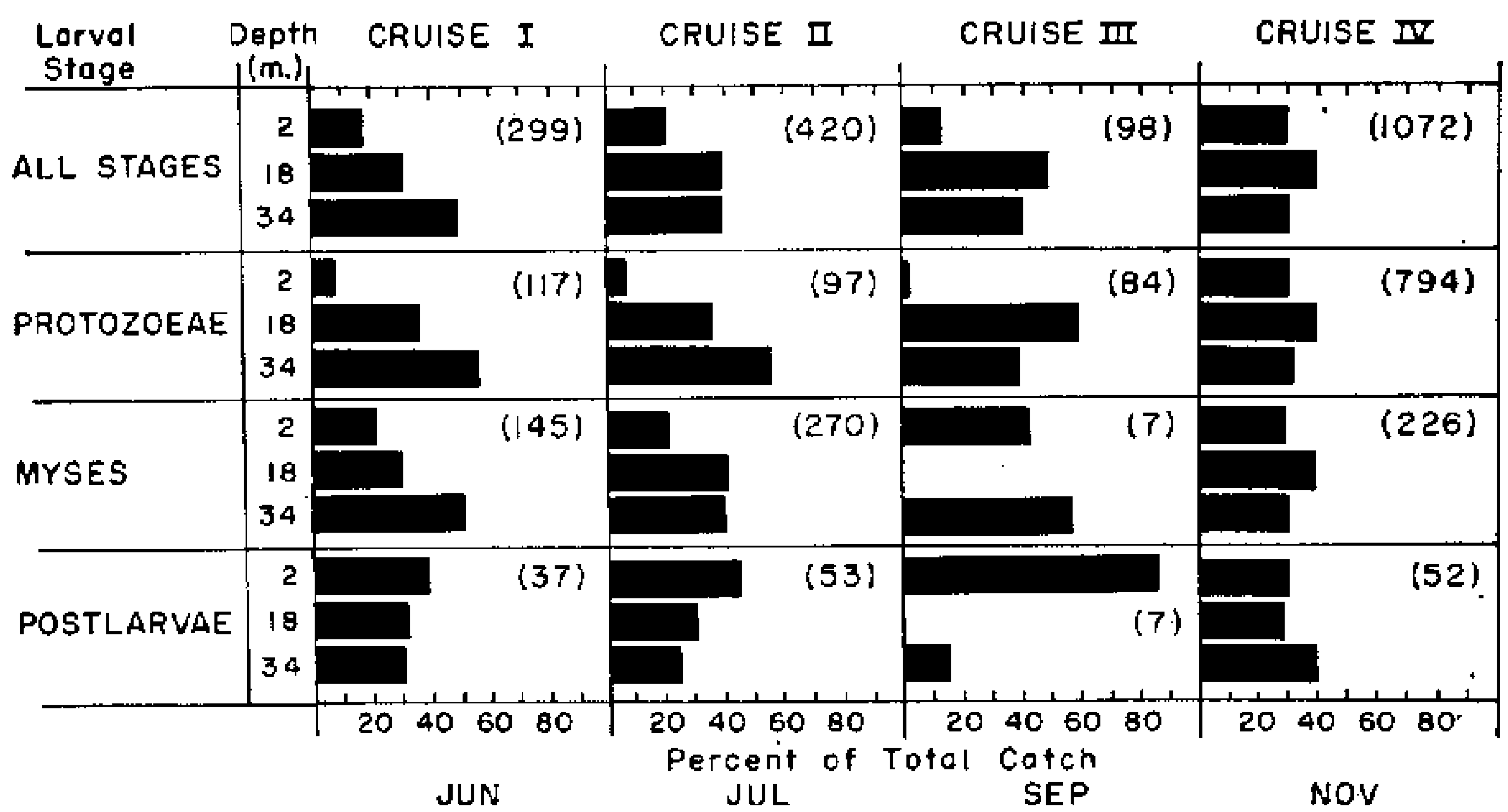

FIG. 3. Depth distribution of immature (planktonic) penaeids.

stage. This reversal is probably related to the animal's increasing mobility permitted by the development of the swimmerets.

The results of the November cruise differed considerably from those of the three previous cruises. Neither the grouped nor the individual-stage data showed any marked differences in depth distribution. Planktonic penaeid forms appeared to be uniformly distributed throughout the water column.

Significance of Temperature

Temperature profiles indicate that a well-defined discontinuity layer was present during the first three cruises, whereas isothermal conditions prevailed within the entire water column in November (Fig. 4). Although measurements of light penetration in the water column were not made, visual observation indicated that the water was extremely clear in June, July, and September but relatively turbid in November. From these observations (temperature profiles and water clarity) it appears that during the first three cruises the water mass was vertically stable with no evidence of vertical mixing, whereas in November it was vertically unstable with vertical mixing. The differences in depth distribution of the planktonic penaeids noted between the first three cruises (June, July and September) and the fourth cruise (November) can be attributed, in part, to the vertical mixing observed in November.

Evidence of Diurnal Migration

Similar short-term changes in the vertical distribution of each planktonic stage were noted in June, July, and September, although the scarcity of planktonic forms and the frequency of non-productive tows make the results of the September cruise of little significance. To illustrate this similarity, the data for each stage were grouped on a 24-hour basis, and average catches were determined for each hour and depth. The results, shown as the percentage of the total hourly catch by depth, are presented in Fig. 5.

These data indicate that various stages of planktonic penaeids do migrate vertically. All stages extended their distribution into the surface layer as darkness descended. The mysis and postlarval stages, however, appeared to migrate at an earlier hour and to remain within the layer longer than did protozoeal stages. These results agree with the

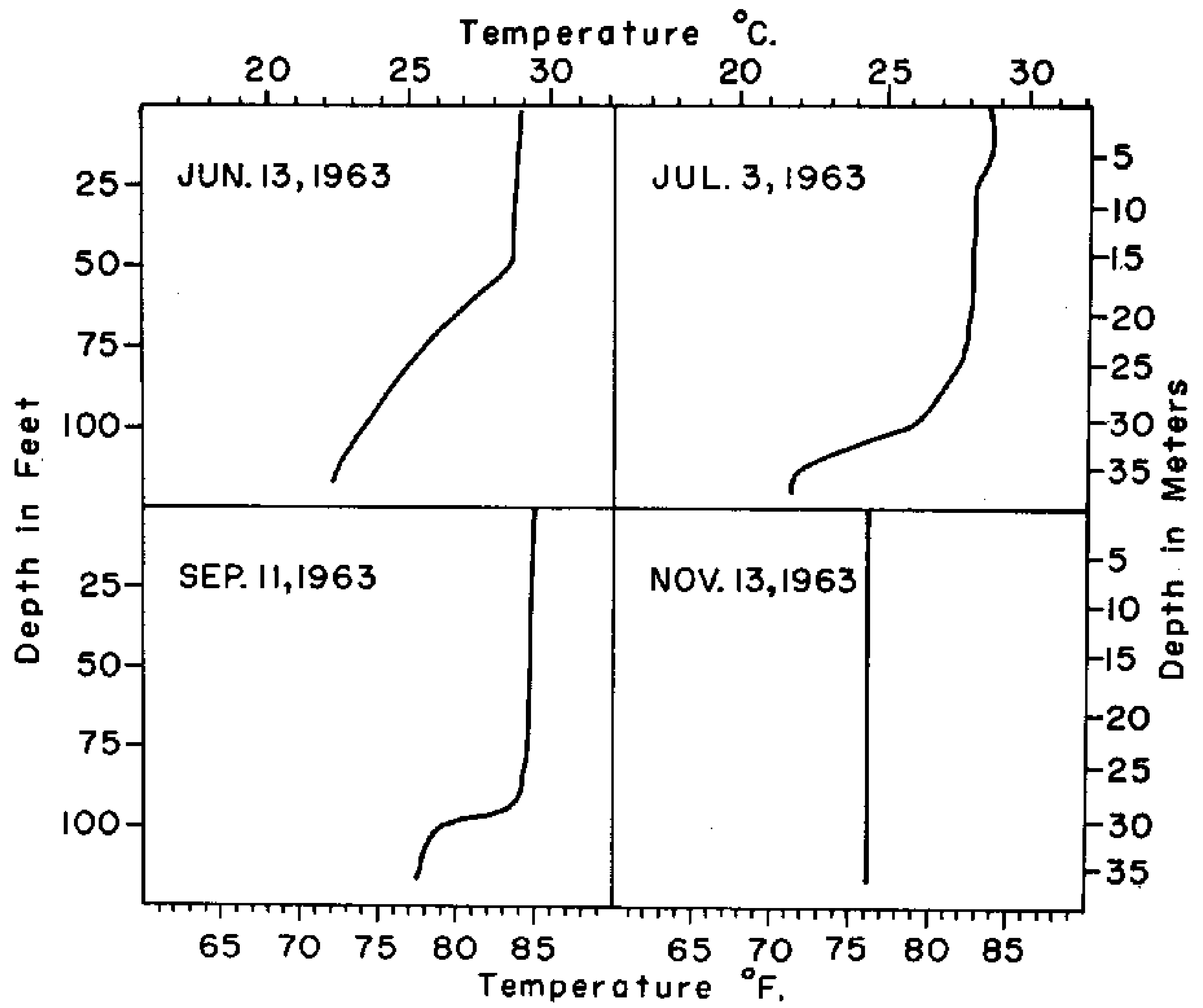

FIG. 4. Temperature profiles at sampling station during vertical distribution studies.

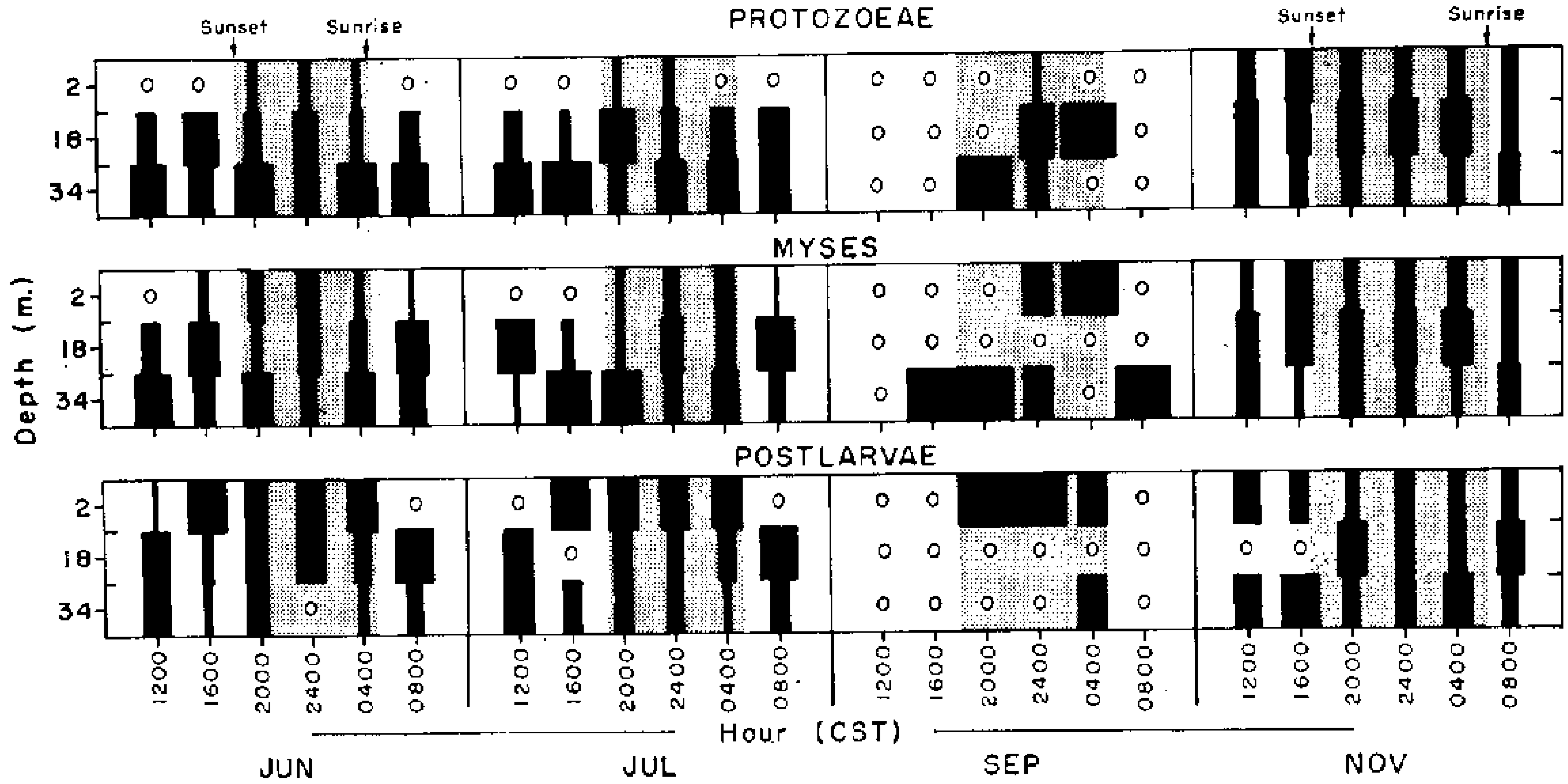

FIG. 5. Variations in the vertical distribution of immature (planktonic) penaeids over a 24-hour period.

findings of Russell (1928) who reported that decapod larvae, in general, extended their distribution into the surface layer with the advent of darkness.

November data gave no evidence of a diurnal migration by any planktonic-stage penaeid. The organisms were, relatively speaking, evenly distributed throughout the water column, probably as a result of the aforementioned vertical mixing.

AVERAGE CATCHES, NIGHT VS. DAY

After all data were grouped by planktonic stage and depth, the average catches during night (2000–0400 CST) and day (0800–1600 CST) were determined for each cruise (Tables 1–4).

TABLE 1

Numbers of planktonic penaeids (per 20 m³ of water filtered) in each sample, June 12–14, 1963

Planktonic stages	Depth in meters	Hours (CST) 2000	2400	0400	0800	1200	1600	2000	2400	0400	0800	Total no.	Total samples	Per cent of total	No. per tow
	2	14	16	11	2	1	8	6	15	14	2	89	10	16	8.9
All stages	18	13	32	10	16	15	11	22	10	28	29	186	10	34	18.6
	34	45	22	36	14	26	7	37	21	37	31	276	10	50	27.6
	Total	72	70	57	32	42	26	65	46	79	62	551	30	100	18.4
	2	2	3	3	0	0	0	2	6	0	0	16	10	7	1.6
Protozoeae	18	7	19	1	5	5	6	11	5	7	7	73	10	32	7.3
	34	22	14	12	5	9	4	19	14	26	14	139	10	61	13.9
	Total	31	36	16	10	14	10	32	25	33	21	228	30	100	7.6
	2	10	13	4	2	0	1	4	7	8	0	49	10	19	4.9
Myses	18	4	12	9	9	5	3	11	5	16	14	88	10	34	8.8
	34	22	8	23	6	12	2	17	7	11	16	124	10	47	12.4
	Total	36	33	36	17	17	6	32	19	35	30	261	30	100	8.7
	2	2	0	4	0	1	7	0	2	6	2	24	10	39	2.4
Postlarvae	18	2	1	0	2	5	2	0	0	5	8	25	10	40	2.5
	34	1	0	1	3	5	1	1	0	0	1	13	10	21	1.3
	Total	5	1	5	5	11	10	1	2	11	11	62	30	100	2.1

TABLE 2

Numbers of planktonic penaeids (per 20 m³ of water filtered) in each sample, July 3–5, 1963

Planktonic stages	Depth in meters	Hours (CST) 2000	2400	0400	0800	1200	1600	2000	2400	0400	0800	1200	1600	Total no.	Total samples	Per cent of total	No. per tow
	2	9	10	15	1	0	4	2	24	13	0	0	4	82	12	20	6.8
All stages	18	15	32	22	10	33	9	7	5	13	15	2	1	164	12	39	13.7
	34	8	27	35	9	9	49	7	18	7	0	0	5	174	12	41	14.5
	Total	32	69	72	20	42	62	16	47	33	15	2	10	420	36	100	11.7
	2	1	5	0	0	0	0	0	0	0	0	0	0	6	12	6	0.5
Protozoeae	18	8	9	7	2	0	3	1	0	4	0	1	0	35	12	37	2.9
	34	3	19	11	2	3	13	0	1	1	0	0	3	56	12	57	4.6
	Total	12	33	18	4	3	16	1	1	5	0	1	3	97	36	100	2.7
	2	6	5	13	1	0	0	2	18	7	0	0	0	52	12	19	4.3
Myses	18	7	22	13	8	29	6	3	5	9	9	1	1	113	12	42	9.3
	34	4	7	23	5	3	33	7	16	6	0	0	1	105	12	39	8.7
	Total	17	34	49	14	32	39	12	39	22	9	1	2	270	36	100	7.5
	2	2	0	2	0	0	4	0	6	6	0	0	4	24	12	45	2.0
Postlarvae	18	0	1	2	0	4	0	3	0	0	6	0	0	16	12	30	1.3
	34	1	1	1	2	3	3	0	1	0	0	0	1	13	12	25	1.1
	Total	3	2	5	2	7	7	3	7	6	6	0	5	53	36	100	1.5

TABLE 3

Numbers of planktonic penaeids (per 20 m³ of water filtered) in each sample, September 10–12, 1963

Planktonic stages	Depth in meters	Hours (CST) 2000	2400	0400	0800	1200	1600	2000	2400	0400	0800	1200	1600	Total no.	Total samples	Per cent of total	No. per tow
	2	1	4	2	0	0	0	2	1	1	0	0	0	11	12	11	0.9
All stages	18	0	47	1	0	0	0	0	1	0	0	0	0	49	12	50	4.1
	34	4	29	0	1	0	0	2	0	1	0	0	1	38	12	39	3.2
	Total	5	80	3	1	0	0	4	2	2	0	0	1	98	36	100	2.7
Protozoeae	2	20	24	16	24	24	26	26	12	18	26	23	12	251	12	32	20.9
	18	0	47	1	0	0	0	0	1	0	0	0	0	49	12	58	4.1
	34	3	28	0	0	0	0	2	0	0	0	0	0	33	12	39	2.8
	Total	3	77	1	0	0	0	2	1	0	0	0	0	84	36	100	2.3
Myses	2	0	1	2	0	0	0	0	0	0	0	0	0	3	12	43	0.2
	18	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0.0
	34	1	1	0	1	0	0	0	0	0	0	0	1	4	12	57	0.3
	Total	1	2	2	1	0	0	0	0	0	0	0	1	7	36	100	0.2
Postlarvae	2	1	1	0	0	0	0	2	1	1	0	0	0	6	12	86	0.5
	18	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0.0
	34	0	0	0	0	0	0	0	0	1	0	0	0	1	12	14	0.1
	Total	1	1	0	0	0	0	2	1	2	0	0	0	7	36	100	0.2

The night-day catch ratios in June, July, and September were 1.6, 1.9 and 53.0 respectively. The comparatively large difference between September's average night and day catches, which yielded a high night-day catch ratio, was believed due to the sporadic occurrence and low density of penaeids in that month, not necessarily any inadequacy of the sampling technique. Larval abundance, as indicated from the results presented in Table 5, was considerably lower in September than during any of the other months. Consequently the variation in numbers of larvae between tows appeared more pronounced and resulted in seemingly biased data. The timing of this cruise apparently did not coincide with the second period of increased abundance of larvae which was expected

TABLE 4

Numbers of planktonic penaeids (per 20 m^3 of water filtered) in each sample, November 12–14, 1963

Planktonic stages	Depth in meters	Hours (CST) 2000	2400	0400	0800	1200	1600	2000	2400	0400	0800	1200	1600	Total no.	Total samples	Per cent of total	No. per tow
All stages	2	28	38	22	31	29	35	29	13	29	33	30	16	333	12	31	27.8
	18	48	46	49	21	20	23	27	19	34	38	51	48	424	12	40	35.3
	34	34	15	21	16	31	20	32	23	19	51	37	16	315	12	29	26.2
	Total	110	99	92	68	80	78	88	55	82	122	118	80	1,072	36	100	29.8
Protozoeae	2	0	2	0	0	0	0	0	0	0	0	0	0	2	12	3	0.2
	18	36	34	38	16	16	14	18	15	24	28	38	42	319	12	40	26.6
	34	24	11	15	14	21	14	20	12	14	39	28	12	224	12	28	18.7
	Total	80	69	69	54	61	54	64	39	56	93	89	66	794	36	100	22.1
Myses	2	5	10	5	6	4	8	3	0	11	5	6	3	66	12	29	5.5
	18	10	9	9	4	4	9	7	2	10	7	13	6	90	12	40	7.5
	34	8	2	3	2	10	4	9	9	4	11	8	0	70	12	31	5.8
	Total	23	21	17	12	18	21	19	11	25	23	27	9	226	36	100	6.3
Postlarvae	2	3	4	1	1	1	1	0	1	0	2	1	1	16	12	31	1.3
	18	2	3	2	1	0	0	2	2	0	3	0	0	15	12	29	1.3
	34	2	2	3	0	0	2	3	2	1	1	1	4	21	12	40	1.8
	Total	7	9	6	2	1	3	5	5	1	6	2	5	52	36	100	1.4

TABLE 5

Average number in night and day samples, all stages and depths combined by cruise

Period	Cruise I June	Cruise II July	Cruise III September	Cruise IV November
Night	22	15	5	29
Day	14	8	<1	30

on the basis of evidence from the synoptic plankton work conducted by laboratory personnel in 1961 and 1962. The night-day catch ratio was 1.0 in November.

Student's "t" test, applied to the mean values for the night and day catches, revealed significant differences at the 95% level during June and July but not in November. Due to the small sample sizes, tests were not made to compare the average night and day catches for either the individual stages or for the September data.

Summary

1. Four research cruises, one each in June, July, September, and November 1963, provided information on the vertical distribution of planktonic-stage penaeids at a 37-meter station in the northwestern Gulf of Mexico, 50 miles south of Galveston, Texas. On each occasion, samples were obtained with a Clark-Bumpus sampler towed at three depths (2, 18, and 34 meters) every four hours over a period of two consecutive days. Tows lasted ten minutes and were made on a circular course around a buoy anchored in about 37 meters of water.

2. In June, July, and September, the data grouped over all stages indicated that planktonic penaeids were most frequent at and below mid-depth (18 meters). Protozoeal stages occurred most frequently near the bottom and postlarval stages at or above mid-depth. This observation suggests that as larval development progresses, the depth of greatest

abundance decreases. In November, planktonic-stage penaeids were more or less uniformly distributed throughout the water column due to the "fall overturn."

3. Temperature profiles and visual observations of water clarity indicated that the water mass was vertically stable during the first three cruises, whereas it appeared to be vertically unstable in November. These seasonal differences in water conditions probably accounted for the change in vertical distribution of planktonic penaeids noted during the November cruise.

4. Each planktonic stage extended its distribution into the surface layer either just prior to or after the onset of darkness.

5. Statistical tests of average night and day catches (all stages and depths combined) in June, July, and November revealed significant differences in June and July but not in November. Average catches in June and July were approximately two times greater at night than during the day.

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